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Relationship between the Density of Larvae of Pandalus kessleri C. and that of Zostera marina L.

by Toshihiro MIZUSHIMA

(Hokkaidō Prefectural Kushiro Fisheries Experiment Station)

Introduction

Zostera marina L. is distributed over a wide area, approximately 35 km^2, in Notsuke Bay.

In a previous report[1)], the author described the distribution chararacteristics of Pandalus kessleri C. larvae over the entire area of Notsuke Bay, and in addition, discussed to some extent the relationship between the distribution of the larvae and the environmental factors. Clarifying the relationship between the distribution of P. kessleri C. larvae and Z. marina L. is important for the creation of fishing grounds for P. kessleri C. and also for the establishment in the future of nurseries for juveniles.

Accordingly, this time, a survey was conducted concerning in particular the relationship between the density of Z. marina L. and

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that of P. kessleri C. larvae. The findings obtained will be reported here.

The author gratefully acknowledges the assistance of the various persons involved in the leadership of the Notsuke Fishermen's Cooperative Association which helped in the survey.

Materials and Methods

The survey was conducted on June 21, 1982 and June 11, 1984, shortly after the hatching of the P. kessleri C. larvae. The survey points were in three areas in Notsuke Bay shown in Fig. 1 - Hadaka-jima, Ryūjin Bay and Onnikuri. Nine survey lines from 200 m to 500 m (abbreviated below as L-1 to L-9) were laid from the beachline on the coast toward the open sea, and points were established on each line at intervals of 50 m to 100 m, the total number of points being 38. L-2 to 7 were surveyed in 1982, and L-1, 8 and 9, in 1984.

Z. marina L. was collected using 25x25 cm quadrats. Two quadrats were collected at each point by scuba divers, and blades above the level of the substrate were obtained. The leaf length, wet weight and number of plants of Z. marina L. were determined, and the density and actual quantity are shown as number of plants/m^2 and kg (wet weight)/m^2 respectively.

P. kessleri C. larvae were collected at each point using a net p. 15
1 m wide, 0.5 m high and 2 m long (1 mm meshes) with a sledge attached,* and at each point a 20 m constant-weight seine was used.* The area of the seine was 20 m^2. The P. kessleri C. larvae collected were brought

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*Translator's note: Literal translation.

to the laboratory after being fixed in 10% Formalin seawater on board ship, and under a stereomicroscope the body length and the instar of the larvae were determined. The average instar of the larvae was calculated by the method of Morris and Bennet[2), 3)].

At the same time, the water temperature in the surface layer and the bottom layer at each point was observed. The depth of water is the value at the average tide level in Notsuke Bay.

Results

1. Depth of Water and Configuration of Seabed

Fig. 2 shows the depth of water and the configuration of the seabed classified by survey line. On the eastern side of the Hadaka-jima lower tidal limit (L-1 to 5), a tendency was observed for the depth to increase gradually from the beachline to the lower tidal limit. For example, in the case of L-1, whereas the depth of water was 0.5 to 0.7 m out to 150 m from the shore, beyond 200 m the gradient increased, and at 300 m the depth was 1.4 m. Beyond 300 m the lower tidal limit was reached, and the depth of water abruptly increased, becoming 2.7 to 3.0 m. p. 16

From 100 m to 300 m in the case of L-4 and 5, the difference in the depth of water depending on the distance from the shore was small, and the gradient was gentle. In the case of L-6 and 7 on the western side of the Hadaka-jima lower tidal limit, the gradient was large from the beachline out to 50 m from the shore, but from 50 m to 200 m the seabed was level. Beyond 250 m the lower tidal limit was reached, and the depth abruptly increased.

In the case of L-8 in Ryūjin Bay, a gradient in the depth of water was observed out to 200 m from the shore. Beyond 200 m, however, there was almost no change in the depth of water. In the case of L-9 at Onnikuri, the seabed was level from 100 m to 400 m with the depth of water at about 1 m, and beyond 500 m the depth increased somewhat. Changes in the depth of water in the case of L-2 and 3, which were established from points corresponding to 150 m from the shore on L-1 to the vicinity of the lower tidal limit were largely the same as in the case of L-1.

2. Ecology of Z. marina L.

1) Density

The density of Z. marina L. at the survey points established on the various survey lines is shown in Fig. 3. At 50 m on L-1 the density was 600 plants/m^2, but at the 100 m and 150 m points it was higher, at 1,000 to 1,200 plants/m^2. Beyond 200 m the density gradually decreaed, and at 300 m it was less than 300 plants/m^2. In this way, the density decreased sharply from the 200 m point out to the lower tidal limit. p. 17 L-2 and 3 also showed the same tendency. The 100 m points on L-4 and 5 showed the highest densities in this survey - 1,100 and 1,400 plants/m^2. Although the density decreased to half - 600 to 700 plants/m^2 - at the 200 m point, it was greater than 500 plants/m^2 even at 300 m, and on this survey line the high-density sector extended over a wide range.

On the other hand, in the case of L-6 and 7, even at the 50 m and 100 m points, where the density was highest, it was about 350 plants/m^2, lower than in the case of the other survey lines. In the case of L-6, the density decreased somewhat the greater the distance

from the shore, but no very important change was observed. In the case of L-7, the density was within the range of 200 to 360 plants/m^2 at each point, and there was no important change. The density was slightly higher in the case of L-8 and 9 than in the case of L-6 and 7, but a general tendency was observed for the density to decrease the greater the distance from the shore. The rate of decrease, however, was not as conspicuous as it was on the eastern side of the Hadaka-jima lower tidal limit. p. 18

2) Leaf Length

The averages of the maximum leaf length of each plant at the various survey points were determined, and these are shown in Fig. 3 as the average leaf lengths. Whereas the leaf length was about 50 cm at the 50 m to 150 m points on L-1, it was greater, 100 cm, at 300 m. In the case of L-2 and 3 as well, leaf length increased the greater the distance from the shore. The leaf length in the case of L-4 and 5 was 60 to 70 cm at each point, and there were no important differences. In the case of L-6 and 7, apart from the fact that the leaf length was somewhat shorter at the 50 m point, no important variation depending on the distance from the shore was observed. In the case of L-8, whereas the gradient in the depth of water was more gentle than in the case of lines such as L-1, 2 or 3, there was a tendency for the leaf length to increase conspicuously the greater the distance from the shore. In the case of L-9, the water was shallow, and the leaf length also was short, less than 50 cm.

3) Actual Quantity

The actual quantity of Z. marina L. at each survey point is shown in Fig. 4. The relationship between the distance from the shore and the actual quantity varied depending on the survey line. For example, in cases such as L-1 and L-8, there was a tendency for the quantity to increase the greater the distance from the shore, in cases such as L-3 and L-6, the quantity decreased further from the shore, and in cases such as L-5, there was almost no change. The survey points at which the actual quantity was greatest were 100 m from the shore on L-6 and L-7, where the quantity was 2.9 kg/m^2, and nowhere did the quantity exceed 3 kg/m^2.

No uniform correlation was observed between the actual quantity at the various points and the density shown in Fig. 3.

3. Density of P. kessleri C. Larvae

The density of the larvae (number of individuals/m^2) on the various survey lines is shown in Fig. 5. On L-1 to 5, in each case the density was high along the beachline, and a tendency was observed for it to decrease the greater the distance from the shore. That is to say, whereas at the 50 m and 100 m points on L-1 the density was 7.0 to 7.4 individuals/m^2, at 200 m it decreased to 3.4 individuals/m^2, the peak occurring at 100 m. In the case of L-2 and 3 as well, roughly the same tendency was shown. In the present survey, L-4 and 5 had the highest densities. At the 100 m point 13.8 and 14.3 individuals/m^2 respectively were recorded, and even at 300 m high densities were shown - 5.8 and 6.3 individuals/m^2 respectively. In contrast to this, in the case of L-6 and 7 on the western side of the lower tidal limit, the density was

p. 19

generally low, although at 50 to 100 m on both lines and at 200 m on L-6 the density was somewhat higher - 1.0 to 1.2 individuals/m^2 and 2.1 individuals/m^2 respectively. Furthermore, variations in density depending on the distance from the shore were small.

4. Relationship between Distance from Shore and Size of *P. kessleri* C. Larvae

The average instar and the average body length of larvae and the water temperature at the lowest stratum at each point on L-1, 8 and 9 are shown in Table 1.

On each survey line there appeared larvae from the first to the fifth instar and higher*, but in the case of L-1, the average instar from 50 m to 150 m was the fourth instar. Beyond 200 m from the shore, however, the third instar became the average, and the greater the distance from the shore, the lower the instar became. In addition, the average body length decreased to less than 9 mm. L-8 as well showed roughly the same tendency as L-1. In the case of L-9, the instar was in all cases lower - the third instar - than in the case of the above-mentioned two lines, but the tendency for the instar to be lower the greater the distance from the shore was not conspicuous.

With regard to water temperature, although the gradient in the case of L-1 was slightly lower, on each survey line the temperature was higher at the beachline, and from the beachline toward the sea a difference in water temperature of 0.5 to 1.3°C was observed.

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*Larvae believed to be in the sixth instar or higher also appeared, but because it is difficult to determine the instar of individuals in the sixth instar or higher, they were treated here as being in the fifth instar. The number of individuals in the sixth instar or higher was small on each survey line.

5. Relationship of Density of Z. marina L., the Actual Quantity [of It] and the Density of P. kessleri C. Larvae p. 20

The correlation between the density of Z. marina L. and that of P. kessleri C. larvae on the various survey lines is shown in Fig. 6. In the case of L-2 to 5 on the eastern side of the Hadaka-jima lower tidal limit, where conspicuous decreases in the density of Z. marina L. from the beachline toward the sea were observed, the coefficient of correlation of the two was $r = 0.83$ (significant at the 1% level), and a positive correlation was observed. In the case of L-1 as well, the same tendency was observed. On the other hand, either the density of Z. marina L. gently decreased from the beachline toward the sea, or, in the case of L-6 and L-7 on the western side of the Hadaka-jima lower tidal limit, where there was almost no change, and L-9 in Onnikuri, no correlation was observed.

There was no correlation between the actual quantity of Z. marina L. and the density of P. kessleri C. larvae, as shown by the relationships (Fig. 7) in L-2 to L-5. This applied also in the case of the other survey lines.

Discussion p. 22

On the basis of the results of the present survey, with regard to the ecology of Z. marina L. in Notsuke Bay, the leaf length showed a positive correlation with the depth of water in which the plants were found, but a negative correlation was observed with the density. In addition, it has been said that in general the density of Z. marina L. and the actual quantity are proportionate[4), 5)], but in Notsuke Bay no proportional relationship was particularly apparent.

The maximum density of Z. marina L. in Japan was reported to be 784 plants/m^2 in Mangoku-ura (Miyagi Prefecture)[5], but in the vicinity of Hadaka-jima to the east in the inner part of this bay, an area of high density comparable with this was found to exist.

With respect to the ecology of this Z. marina L., according to Kikuchi[6), 7)], the reason why juvenile fish and small-sized fish are plentiful in submarine forests is that these areas function as shelters in which fish can take refuge from enemies, the direct rays of the sun and water currents, and they function as feeding grounds because small animals that serve as food are plentiful. There are, however, very few reports dealing specifically with the relationship between animals useful in terms of fisheries inhabiting submarine forests and the ecological characteristics of Z. marina L.

On the basis of the previous report[1)] and the present survey, it is believed that there is a complex relationship among the environmental factors determining the distribution of P. kessleri C. larvae, depth of water, water temperature, salt concentration, flow of seawater, ecological characteristics of Z. marina L., food animals, distribution of parent P. kessleri C. at the time of hatching, and other factors affecting the living conditions of the larvae.

With regard to the relationship with density among the relationships involving the ecology of Z. marina L., two different patterns of density of P. kessleri C. larvae were observed depending on the density gradient from the beachline toward the sea. In one case, in

areas where the density gradient was steep, for example, the eastern side of the Hadaka-jima lower tidal limit, where the density at the beachline exceeded 800 plants/m^2, there were many places where the density of P. kessleri C. larvae was greater than six individuals/m^2, and a positive correlation was observed between the two. In the other case, in areas where the Z. marina L. density gradient was shallow and the density was also low, for example, the western side of the Hadaka-jima lower tidal limit and the Onnikuri area, the following characteristics were observed: the change in the density of P. kessleri C. larvae from the beachline toward the sea also was small, and the density was low as well. p. 23

With regard to the relationship between the density of P. kessleri C. larvae and the actual quantity of Z. marina L., it was reported previously[1] that at points where the actual quantity of Z. marina L. is greater than 1 kg/m^2, a tendency was observed for the larvae also to be plentiful, but this time no such relationship was particularly apparent. Further surveys will be necessary in order to clarify this point.

In addition, nothing definite can be said with regard to the reason why the density of P. kessleri C. is high in places where the density of Z. marina L. is high, because at the present time there are no specific data concerning organisms that can serve as food. It is believed, however, that together with the flow of seawater, discussed below, the two functions - as a refuge and as a feeding ground - pointed out earlier by Kikuchi[6) 7)] are important determining factors.

With regard to the relationship with the flow of seawater, in the survey reported previously[1] covering the entire bay, it was shown that the high-density area for P. kessleri C. larvae was formed in the

innermost part of the bay, the area of convergence of the tidal currents, rather than in the vicinity of the lower tidal limit at the centre of the bay, where there is an extremely large flow of seawater caused by tidal currents. The same phenomenon was observed in the relationship whereby the density was low in the vicinity of the lower tidal limit and high along the beachline, as in the case of the eastern side of the Hadaka-jima lower tidal limit even in the same innermost part of the bay. Furthermore, in the most recent survey, a considerable difference was observed in the densities of larvae at high and low tide along the beachline and furthest from the shore on the same survey line (unpublished). This can be said to suggest that tidal currents have an effect on the bringing together and the dispersion of larvae.

With regard to the growth of the larvae, the fact that a tendency was observed for the average instar to be higher at the beachline than further from the shore shows that growth is good at the beachline. This difference in average instar is consistent with the water-temperature gradient at this time, but on the basis of the relationship between water temperature and growth in the lower instars in this species,[8] it is believed that water temperature has an effect on the growth of the larvae.

At the present time, it is not known whether or not, in contrast to this hypothesis, the hypothesis that "P. kessleri C. migrate" can be established; that is to say, it is not known whether or not [P. kessleri C.] acquire selectivity with respect to water temperature as they grow, and move to the beachline where the water temperature is high. This species receives nourishment from the egg, the hatched larvae do not

have a free-swimming stage, and the animal moves by creeping, but it will be necessary in the future to shed light on the resistance of the larvae to tidal currents and on the question of transportation as well.

In subsequent surveys it was shown that there is a tendency for larvae, as they grow, to migrate further from the shore after three to four months, but the author intends to report on this point at another time. p. 24

Finally, it can be said that the relationship between P. kessleri C. larvae and the density of Z. marina L. determined by this survey suggests a necessary condition for the selection and preparation of [sites for] nurseries for juvenile P. kessleri C.

Summary

For six months in both 1982 and 1984, nine survey lines were established in three areas of Notsuke Bay. The relationship between the ecology of Z. marina L. and the density of P. kessleri C. larvae was surveyed, and the following findings were obtained.

1. The leaf length of Z. marina L. showed a positive correlation with the depth of water and a negative correlation with the density. No correlation was observed between the density and the actual quantity of Z. marina L.

2. In the case of survey lines on which the density gradient of Z. marina L. from the beachline toward the sea was conspicuous, a positive correlation was observed between the density of Z. marina L. and that of P. kessleri C. larvae.

3. On the other hand, in the case of survey lines on which the density gradient of Z. marina L. was flat and the density as well was low, the density of P. kessleri C. larvae also was low.

4. No correlation was observed between the actual quantity of Z. marina L. and the density of P. kessleri C. larvae.

5. A tendency was observed for the average instar of P. kessleri C. larvae to be lower the greater the distance from the beachline.

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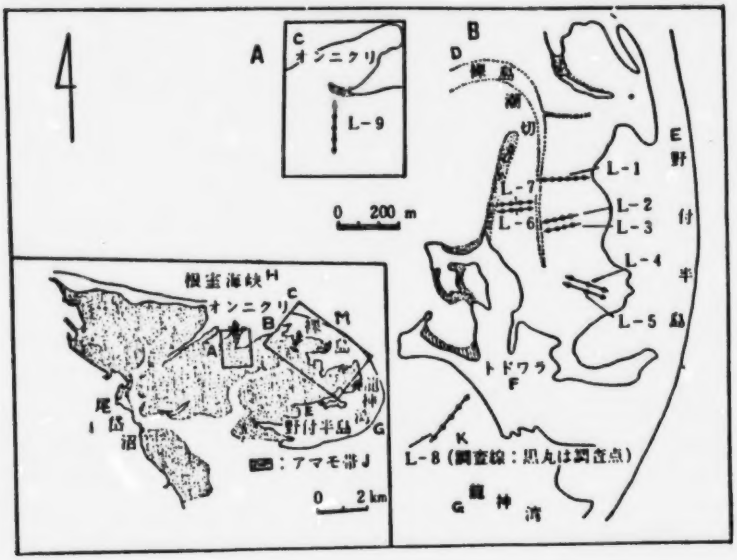

Fig. 1. Survey Areas and Survey Lines in Notsuke Bay

Key:

C. Onnikuri, D. Hadaka-jima Lower Tidal Limit, E. Notsuke Peninsula, F. Todowara, G. Ryūjin Bay, H. Nemuro Strait, I. Odaitō, J. Z. marina L. zone, K. (Survey line; black dots indicate survey points); M. Hadaka-jima.

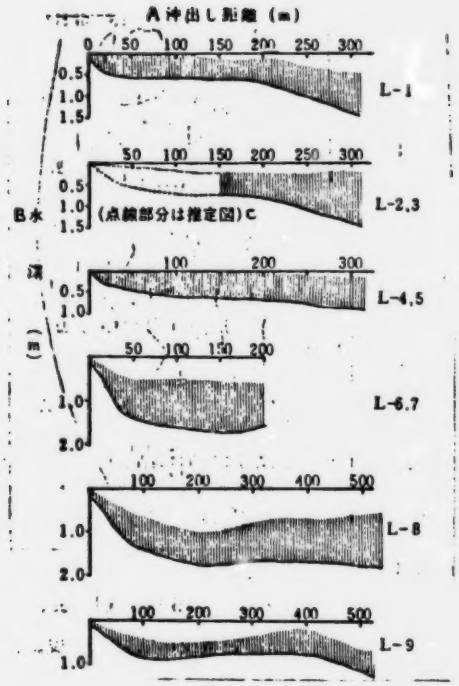

Fig. 2. Depth of Water and Configuration of Seabed on Survey Lines (Section formed by continuous lines above seabed indicates habitation zone and leaf length of Z. marina L.)

Key:
A. Distance from shore (m), B. Depth of water (m), C. (Dotted lines indicate inference).

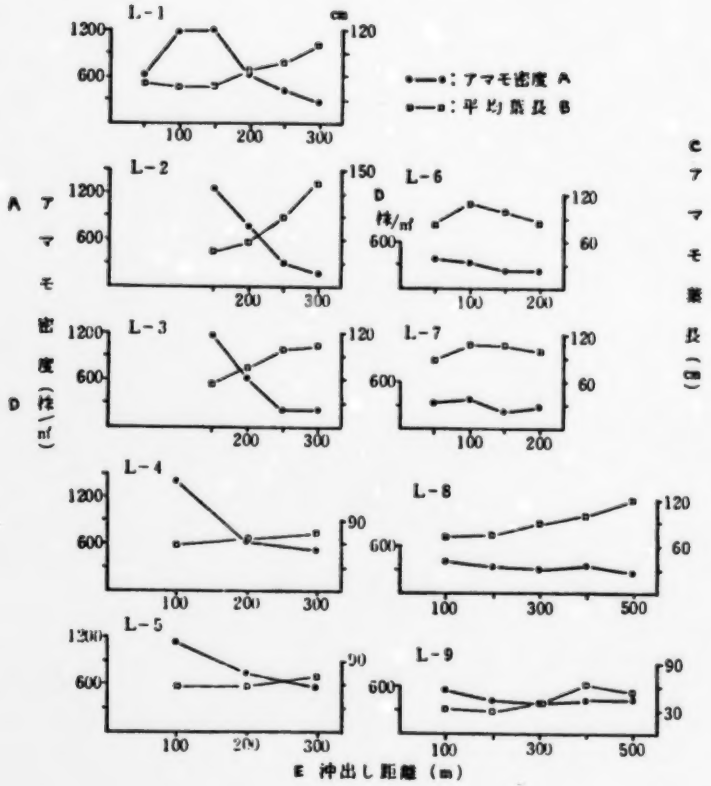

Fig. 3. Density and Average Leaf Length of Z. marina L. Classified by Survey Line

Key:
A. Density of Z. marina L., B. Average leaf length, C. Leaf length of Z. marina L. (cm), D. (Plants/m^2), E. Distance from shore (m).

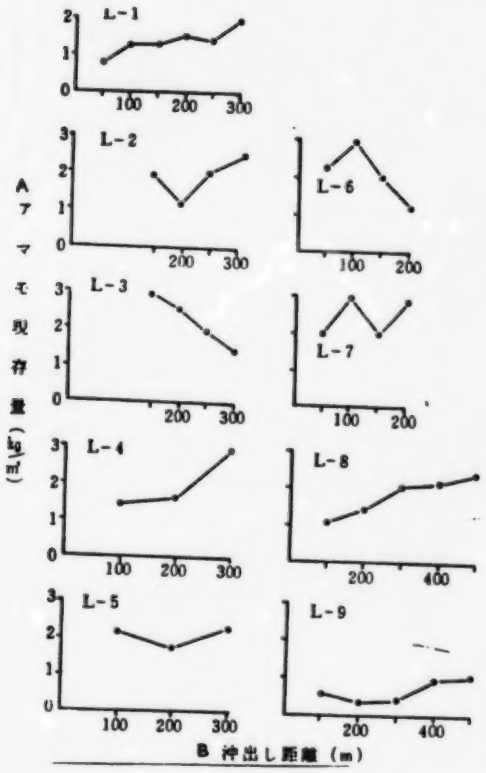

Fig. 4. Actual Quantity of Z. marina L. Classifed by Survey Line

Key:

A. Actual quantity of Z. marina L. (kg/m^2), B. Distance from shore (m).

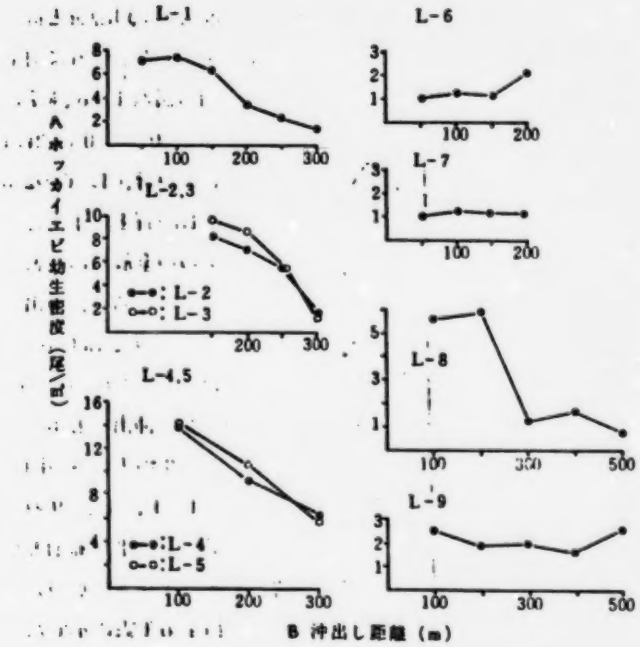

Fig. 5. Density of P. kessleri C. Larvae Classified by Survey Line

Key:

A. Density of P. kessleri C. larvae (individuals/m^2), B. Distance from shore (m).

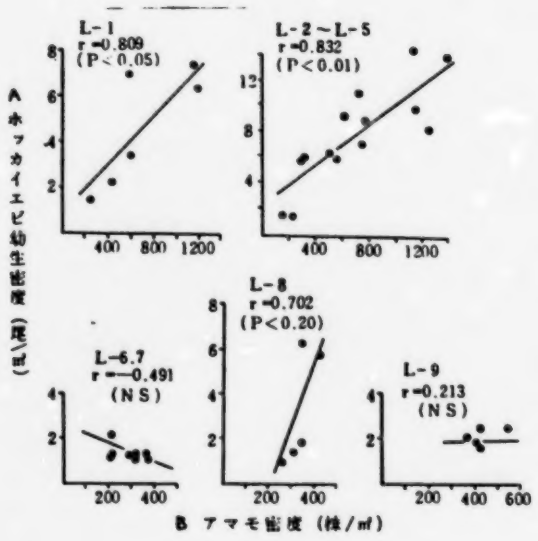

Fig. 6. Relationship between Density of P. kessleri C. Larvae and That of Z. marina L. Classified by Survey Line (NS: No significant difference)

Key:

A. Density of P. kessleri C. larvae (individuals/m^2), B. Density of Z. marina L. (plants/m^2).

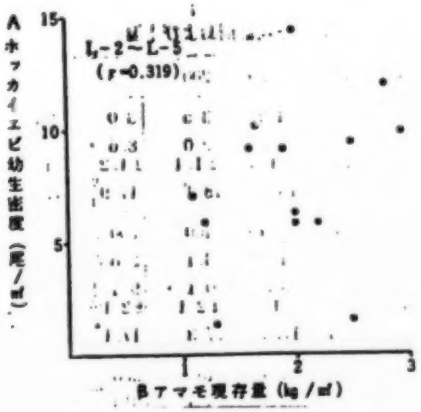

Fig. 7. Relationship between Density of P. kessleri C. Larvae and Actual Quantity of Z. marina L. on Survey Lines L-2 to L-5

Key:

A. Density of P. kessleri C. larvae (individuals/m^2), B. Actual Quantity of Z. marina L. (kg/m^2).

Table 1. Distance from Shore, Body Length and Average Instar of P. kessleri C. Larvae and Water Temperature

A 調査線	B 神出し距離(m)	50	100	150	200	250	300
L-1	C 平均齢期	4.3	4.1	4.2	3.5	3.0	3.1
	D 平均体長 (mm)	10.2 ±1.2	9.8 ±1.7	9.6 ±1.6	9.0 ±1.4	8.6 ±1.2	8.9 ±1.3
	E 水温 (℃)	18.4	18.3	18.3	18.1	17.9	17.8
L-8	B 神出し距離	100	200	300	400	500	
	C 平均齢期	4.9	4.0	4.0	3.1	3.6	
	D 平均体長	10.9 ±2.0	9.6 ±1.6	9.8 ±1.8	9.1 ±2.1	9.4 ±2.1	
	E 水温	18.4	17.4	17.3	17.3	17.1	
L-9	B 神出し距離	100	200	300	400	500	
	C 平均齢期	3.7	3.4	3.7	3.6	3.3	
	D 平均体長	8.9 ±1.4	9.3 ±1.5	8.9 ±1.4	8.7 ±1.1	8.5 ±1.7	
	E 水温	18.5	18.8	18.5	18.4	17.2	

Key:

A. Survey line, B. Distance from shore (m), C. Average instar, D. Average body length (mm), E. Water temperature (°C).
The number of specimens was 20 at each point.